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QUANTITATIVE EVALUATION OF DISTURBANCES ASSOCIATED WITH SKI AREA DEVELOPMENT

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Final Report

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Quantitative Evaluation of Disturbances Associated with Ski Area Development

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INTRODUCTION

Winter recreation demands have resulted in substantial ski area development of forested areas. These developments, with the associated roads, sewage systems, and ski trails are built in the same high mountain areas that provide New Mexico with most of its water. Because these forested mountains are effective in preventing loss of nutrient capital, the quality of water from these areas is very good. A disturbance interfers with this ability and can cause increases in siltation and in nutrient content of the water leaving the area. Analyses of the water can determine the effects of a disturbance on an ecosystem, indicate tolerable limits on the level of disturbance, and the changes in water quality for downstream users. The potential value of water quality as a tool to evaluate land management results because of the nutrient and energy linkages that exist between terrestrial and aquatic systems (Likens and Bormann 1974). Because of these linkages the effects of a disturbance to the terrestrial system are often transmitted to aquatic systems.

Life depends on a supply of chemical elements all of which tend to circulate in the biosphere in characteristic pathways. Recognition of the importance of these element pathways (cycles) to man's activities has generated intensive study of biogeochemical processes. Studies of nutrient budgets and cycles have become a popular method of analyzing ecosystems as projects in the Northeast, Southeast, Northwest, and Southwest are using cycles of elements to characterize the efficiency of undisturbed ecosystems (Likens and Bormann 1972, Gosz et al. 1972, 1973, Gosz 1975, Johnson and

Swank 1973, Cole et al. 1973). A significant result of these studies has been the identification of the conservative nature of undisturbed ecosystems with respect to their nutrient capital. An efficient biotic community, in terms of storing and cycling processes, has less nutrient capital flushed from the system via the drainage water. The ability of natural systems to maintain nutrients is partially the result of the biological processes within that system and any change imposed on those processes often affects the ability of a system to maintain its nutrient status. This has been shown in numerous studies by the increased nutrient levels in the drainage water of the area after disturbance. Stream transportation (dissolved and particulate material) has been particularly useful in evaluating the efficiency of an ecosystem in conserving its nutrient capital. If output studies (by stream transportation) are accompanied by studies of inputs to the system (precipitation and sedimentation), then it is possible to gain a comprehensive view of the dynamic status of the ecosystem. This watershed approach to studies of nutrient cycling is very popular because of its advantages in evaluating interrelationships between biota, nutrient cycles, hydrologic cycle, and energy flow in a single system (Bormann and Likens 1967). It also makes it possible to compare different ecosystems or to evaluate the effect of land management practices on ecosystems.

The effect of a particular land management practice may be evaluated in two ways: 1) in terms of the effect on the land area itself (e.g. loss of nutrient capital, reduced productivity) or 2) the effect of the change of stream parameters on stream organisms

(e.g. eutrophication). In either way the study of water quality can provide valuable data in the evaluation of the effect. The objective of this paper is to demonstrate the use of water quality as a tool in evaluating disturbances to natural land and water systems. Specifically, it evaluates the development and operation of a ski area on a spruce-fir forest ecosystem and its stream in New Mexico. Studies have been made of a series of developments representing increasing impact severity to a single area as well as different areas subject to different types of impacts. The relative importance of each type of disturbance is documented in terms of its effects on water quality. The long term goals of this research are to identify the tolerance levels of the terrestrial and aquatic portions of this ecosystem to ensure its health and self-maintenance properties.

Although the research period of this cooperative agreement was from June 1974 through June 1975, I will present data for two water years (Oct. 1972-Sept. 1973, Oct. 1973-Sept. 1974). My computer programs are designed for data for a complete water year, therefore, I am not able to make a quantitative analysis for all of the study period at this time. A preliminary analysis of recent data indicates trends similar to those of the 1972-73 and 1973-74 water years and I am confident that the results reported here will be confirmed by the 1974-75 data.

STUDY AREA

The study area is the Santa Fe Ski Basin located about 15 km northeast of Santa Fe, New Mexico in the Sangre de Cristo Mountains. The ski basin is located at the headwaters of the Rio en Medio,

a perennial stream. Present and planned developments of the ski area provide a unique opportunity to study the impact of several types of disturbances. The ski basin watershed can be divided into three areas based upon types of useage and topographic boundaries (Fig. 1). The upper area (area 1; 163 ha) is only affected by skiing activity (ski runs, poma lifts) and the stream is gauged which gives us detailed water discharge rates and yield data. Prior to the summer of 1972 area 1 was similar to an undisturbed watershed. Only limited skiing occurred as a result of a poma lift and a single ski run located along the south boundary of the watershed. During September and October 1972 the poma lift along the south boundary of area 1 was replaced with a new poma lift (Model T210). The major impact was that of constructing new concrete piers for the towers. Approximately 78 m^3 (102 cu yds) of concrete were used for the 15 towers and bottom foundation.

During the summers of 1973 and 1974, an additional poma lift (Model H90) was constructed in the center of area 1 along the stream. This poma lift consists of 14 towers traveling about 1160 m (3800 ft) horizontally (300 m vertical lift). The major construction activity consisted of blasting to remove boulders in the lift path and pouring concrete footings for the towers. About 61 m^3 (80 cu yds) of concrete was required for the entire lift. The lift required very little tree removal since it was placed in a relatively open area.

During the summer of 1974, two ski runs were cleared in area 1 to serve the Model H90 poma lift. Again, because of the rather open terrain concerned, the number and basal area of trees removed

was small. A total of 907 stems ranging from 2 to 33 cm (1 to 13 inches) diameter (stump height) were cut, however, because of the abundance of small trees (average stem diameter was 9.4 cm) the total basal area removed amounted to only 7.3 m^2 (68.5 sq ft) on an area of about 2 ha.

The middle portion of the ski basin (area 2; 92 ha) is the drainage area for most of the ski runs plus a chair lift, a parking lot, drainfields from the waste disposal systems of two lodges, and 0.8 km of road subject to road salting practices. A stream diversion, consisting of a gate dam and underground pipe, diverts the stream from area 1 out of the study area (Fig. 1). Therefore, water quality data collected from area 2 reflect impacts on that area only.

The lower portion of the ski basin (area 3; 4.9 ha) does not have skiing activity, however, it is affected by a parking lot and 0.5 km of road which is subject to road salting practices during the winter.

The vegetation of the ski basin is primarily Engelmann spruce (Picea engelmannii Parry) and corkbark fir (Abies lasiocarpa) var. arizonica (Meriam) Lemm.) with small areas of aspen (Populus tremuloides Michx.) scattered throughout the basin below 3355 m (11,000 ft). Alpine tundra occurs on a small area above 3660 m (12,000 ft). A detailed report of the topography and climatic factors is available (Gosz 1975).

METHODS AND PROCEDURES

Quantification of precipitation, streamflow, and the concentrations of nutrients entering and leaving the basin allow a calculation of

nutrient flux for individual areas of the watershed. Although a number of nutrients and heavy metals are under investigation, this report deals only with calcium, magnesium, sodium, potassium, nitrate-N, and chloride.

Precipitation was recorded by a combination of standard and recording rain gauges. During the period Oct. 1971-Sept. 1973, three precipitation stations were in service at 2377, 2987, and 3292 m elevation. Since September 1973, seven precipitation stations have been in service over the elevational gradient at approximately 300 m intervals. Regressions of precipitation on elevation were calculated for annual precipitation and applied to individual areas of the ski basin to estimate the weighted areal precipitation (see Gosz 1975). Rainfall samples for chemical analysis were collected weekly from polyethylene collectors described by Likens et al. (1967). The design of these collectors eliminates concentration of solutes by evaporation. Snowfall was collected in large plastic "garbage cans" (about 2 m above the ground) lined with clean plastic bags. The bags were removed and closed, preventing contamination during transit to the laboratory. The precipitation samples contained chemicals from dry fallout, thus, the analyses estimate bulk precipitation. Samples contaminated by bird droppings, etc., were disregarded. The product of precipitation volume and chemical concentration estimate the nutrient input for the area under study.

Streamflow was measured continuously at the base of area 1 by a gaging station. During winter months the weir was heated to prevent ice from forming on the V-notch. Areas 2 and 3 are not

gauged, therefore, discharge volumes were estimated using the weighted areal precipitation and evapotranspiration data for the elevational range of the ski basin (see Gosz 1975).

The water diversion which transfers water from area 1 outside the ski basin has a capacity of 1.95 cfs. During 1973-74 stream discharge from area 1 did not exceed that capacity, however, during 1972-73 discharge rates were significantly higher during the spring snow melt period causing the stream to overflow the diversion and enter the stream system of areas 2 and 3. The volume of water entering the lower areas was calculated from the difference between 1.95 cfs and the actual discharge rate of area 1.

Samples of stream water for chemical analysis were collected weekly at the base of each area of the ski basin except during periods of high discharge when more frequent sampling occurred. More frequent sampling also occurred from area 1 during periods of construction activity (e.g. during blasting operations). The samples were collected in 500 ml acid washed polyethylene bottles and acidified to prevent chemical change.

Cation chemical analyses were performed on a Perkin-Elmer Model 306 Atomic Absorption Spectrophotometer. Sodium and K^+ were analyzed directly from sample bottles, however, Ca^{++} and Mg^{++} analyses were made after pretreatment with a lanthanum-HCl buffer to avoid interferences (Slavin et al. 1963). Nitrate-N was analyzed by the ultraviolet procedure (Standard Methods 1971) and chloride was analyzed by a chloride specific ion electrode. The product of stream volume and chemical concentration estimates nutrient output from a watershed. It was necessary to use the water year (October

through September) to calculate annual output because of significant snowfall during October through December which does not leave the watershed until the following spring.

RESULTS AND DISCUSSION

HYDROLOGY

This paper presents data for two years, Oct. 1972-Sept. 1973 and Oct. 1973-Sept. 1974. These two years were very different hydrologically which is fortunate because our results should reflect the range of variation that would be encountered in this area. Table 1 shows hydrological data for the 3 areas of the ski basin which demonstrates the variability that can occur on a year to year basis in this semiarid climate.

Approximately 75% of the above average precipitation in 1972-73 occurred as snow and the resulting spring snow melt caused runoff to greatly exceed evapotranspiration. During 1973-74 the much smaller precipitation volume went primarily into soil moisture recharge (resulting from the very dry preceeding summer and fall) and evapotranspiration became a dominant factor. This can be readily seen in Figure 2 which shows the significant difference in stream discharge during the two-year period. It should be obvious that these results will play an important role in any discussion of stream chemistry.

STREAM CHEMISTRY

Although stream discharge varied by as much as a 5-fold difference between the two years, natural stream chemistry variation (area 1) was much less (Fig. 3). Seasonal patterns did

occur with low concentrations associated with the high discharge volumes during the spring snow melt. Sodium and Ca^{++} showed the most pronounced seasonal patterns, however, all four cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) in the stream water of area 1 were significantly, negatively correlated with stream discharge for both study years. The major difference between the two years was that cation concentrations were most highly correlated with the log of the discharge rate during the very wet year and directly with the discharge rate during the dry year. The major difference between a wet and dry year in terms of cation concentrations in natural stream water of this area seems to be a slight dilution effect during the wetter year. Nitrate levels were low and very consistent during the 2-year period and as a result this nutrient was not correlated with discharge or other cation concentrations in the stream water of area 1.

Of all ions studied Ca^{++} was demonstrated to be the most variable and the variation was higher during the wet year than during the dry year. Much of this variation appears to be the result of the affinity which the divalent ion Ca^{++} has for exchange sites on soil and organic colloids and the amount of water moving through the soil (resulting in stream flow) which can remove Ca^{++}. Since stream discharge varies throughout the day, sampling at different times of the day can account for a certain amount of variability in the data. Another factor which may add to the Ca^{++} variability is Ca^{++} held on exchange sites of the suspended particulate load of the stream. Because of its replacing ability Ca^{++} would be the dominant cation held by this material (Brady 1974,

White 1975). The particulate load of a stream generally is positively correlated with discharge (Bormann et al. 1974) and this factor may be partly responsible for the Ca^{++} variability. Although these daily patterns tend to show a positive relationship between Ca^{++} concentrations and discharge, the overall effect of spring snow melt is that of dilution and its dominance causes a significant negative correlation between cations and discharge on an annual basis.

Clearing of ski runs and poma lift construction did not appear to significantly affect the water chemistry of area 1 (Fig. 3). The large peaks for Ca and K in October 1972 were the only occurrences which may be attributed to poma lift construction. The occurrence of the peaks resulted from rain on three consecutive days (2.2 cm) following a two week dry period. Stream discharge increased significantly causing higher levels of all cations in the stream water. This same pattern happened on other of our study watersheds, however, the increase was not as pronounced.

Construction of the model H90 poma lift in the center of area 1 represents a more significant impact since it is closer to the stream, disturbed new land, and required blasting to remove boulders from the construction site. Through all of this activity during the summer and fall of 1973, stream chemistry varied little In this case the reason appeared to be the lack of rain as the summer and fall months were very dry. Several small peaks can be seen during September and October which were correlated with precipitation events, however, because of the low soil moisture, little runoff occurred. Higher moisture levels would no doubt have

caused significantly higher erosion and increased concentrations of cations.

The clearing of vegetation during the summer of 1974 did not significantly alter concentrations of cations or anions. A number of studies have demonstrated that ions such as Ca^{++}, Mg^{++}, K^{+}, and nitrate-N increase significantly in stream water after vegetation clearing (Likens and Bormann 1972, Likens et al. 1970, Bormann et al. 1968, U.S. Forest Service 1971, Fredriksen 1970). Weighted average concentrations of nitrate-N in the stream water of area 1 did not differ between the 1972-73 and 1973-74 water years (0.39 mg/l) nor was there any increase during or after the tree removal activity. The small fluctuations in cation concentrations shown in Figure 3 are a function of discharge volume and do not seem to be related to tree removal since they also occur in the streams of other watersheds. The reason is no doubt related to the small area cleared, the low density of trees with grass cover in open areas, and the small size of individual trees. Another factor may be the method of cutting. Since most individuals were growing in the open, they had branches down to the ground. The stems were cut above the lowest whorl of branches for the purpose of holding the snow pack, however, this also had the effect of keeping the root system alive and functioning. Data is not yet available for the 1974-75 water year, therefore, we cannot say if increased N levels occur with time after the cutting.

The middle portion of the ski basin (area 2) is the area of most activity. Figure 4 demonstrates the difference in stream chemistry between areas 1 and 2. Since the stream from area 1 is

normally diverted out of the ski basin the difference in water quality reflects a difference in land use. Cation concentrations were always higher in area 2 than in area 1 and more variable with Ca^{++} and Na^{+} showing the largest change (Table 2, Fig. 4). The pronounced pattern of lower cation concentrations during the high spring stream discharge also was affected. During 1972-73 the very high spring discharge rates caused a dilution, however, during 1973-74 the much smaller spring discharge was accompanied by higher cation concentrations than the preceeding winter. One explanation for this difference may be the fact that the capacity of the stream diversion system was exceeded during the 1972-73 year and the overflow of water from area 1 may have diluted cation concentrations in area 2. In 1972-73 the cations in the stream water of area 2 generally were significantly, negatively correlated with discharge, however, the 1973-74 water year shows non-significant or positive correlations with discharge. These results further support the contention that significantly different factors affecting stream chemistry are involved in the two areas.

The levels of nitrate-N in the stream water of area 2 were not related to stream discharge, however, they were significantly higher and more variable than those from area 1 (Table 2). The drainfields of the sewage disposal system are thought to be the source of this nutrient. This will be discussed more later in this report.

Area 3 shows higher cation concentrations than either area 1 or 2 (Table 2, Fig. 5). The stream water from area 2 also flows through area 3, therefore, relations between discharge and ion concentrations are similar to those from area 2. However, the

difference in the magnitude of the concentrations between areas 2 and 3 identify additional effects occurring in area 3. Calcium and Na^+ were the ions most significantly affected.

The higher concentrations of all ions in areas 2 and 3 (Table 2) represent a deterioration of water quality, however, the increases generally are not large enough to affect downstream organisms. The ion which comes closest to pollution levels is Cl^- which reached concentrations as high as 55 mg/l (March 31, 1974) for a brief period. This level does not exceed the tolerance levels for any native fish (trout are affected by 400 mg/l, McKee and Wolf 1963) and of stream invertebrates only the Tendipedidae or midges have fresh water species with tolerances below 10 mg/l (Tarzwell 1965). It is not known if Tendipedid species have been affected in the stream below the ski area.

Chlorides are considered to be among the most troublesome anions in irrigation water, however, concentrations of Cl^- in the stream water have not reached levels reported harmful to plants (McKee and Wolf 1963). According to the irrigation water classification shown in McKee and Wolf (1963) the water of all three areas of the ski basin can be used on almost all soils and for almost all crops without detrimental effects.

Since the three areas differ in size and, therefore, volume of water discharged, concentration differences only reflect the degree of change. Calculating the total loss or output from each of these areas demonstrates the magnitude of the difference. Table 3 lists the total cation loss per unit area (kg/ha) for each of the 3 areas. These values again show increased losses from

area 1 to area 3, however, the increase from area 2 to area 3 is the most pronounced. Again, Ca^{++} and Na^{+} show the greatest degree of change. The major question now involves the source of cations being lost from the basin. Are they lost from within the system, which may affect future productivity, or do these quantities come from inputs to the system both natural (i.e. precipitation) and man-caused (i.e. road salt, sewage)? Table 3 also shows cation inputs to the area in precipitation calculated from studies of precipitation chemistry and volumes. Cation inputs per unit area were very similar over the three areas of the ski basin and cannot explain any of the differences seen in the outputs. As a result of the similarity of inputs the patterns of cation flux, or net loss, were very similar to those of cation output.

The two major man-caused inputs to the system were sewage effluents from the lodges and road salt. It is difficult to measure the quantity of sewage effluent in the ski area because of the use of septic tanks and drain fields. The best approximation is through an estimate of the quantity of water going through the waste disposal system. The nutrient concentrations used to calculate total nutrient quantities were taken from Metcalf and Eddy (1972) and should give reasonable estimate of septic tank effluent (Segall, personal communication). Sewage effluent concentrations of Cl^{-}, Na^{+}, Ca^{++}, Mg^{++}, and K^{+} used were 215, 155, 50, 32, and 8.8 mg/l, respectively. It is estimated that 20 gal/day per capita enters the sewage system of this recreational development (Metcalf and Eddy 1972). The number of skiers ranged from 60,000 to 75,000 per ski season which is taken to be 100 days (Pitcher,

personal communication). These figures yield an estimate of the total kg of nutrients added to area 2 in the sewage systems (Table 4).

Road salt comprised the other major man-caused input of nutrients to the basin. Approximately 1750 kg of a sand-salt mixture were applied per mile of road during each salting trip. Chemical analysis of the salt mixture showed it to be 16.7% Cl^-, 9.8% Na^+, 0.3% $SO_4^=$, 0.13% Ca^{++}, 0.08% K^+, and 0.015% Mg^{++}. The remainder was mineral sand (less than ¼ in dia.). Approximately 40 salting trips were made during the winter of 1972-73 which yields total inputs of nutrients via road salt shown in Table 4. A comparison of natural and man-caused inputs shows that road salt supplied the largest total quantity of nutrients primarily as NaCl, sewage effluent supplied the majority of Mg^{++}, and precipitation supplied the majority of Ca^{++} and K^+. Table 4 also shows the total outputs (in stream water) of these nutrients during the 1972-73 year which, except for Na^+ and Cl^- in area 2, were much greater than the inputs. In area 2 the greatest net loss occurred for Ca^{++}. The reason would seem to be the mass action replacement of Ca^{++} held to exchange sites in soil by the large quantities of Na^+ added to the system (Brady 1974). Significant quantities of Mg^{++} and K^+ were lost from the system by the same action. Area 2 showed a net increase in Na^+ and Cl^- for the year, however, the distribution of this material is not known. Sodium may be occupying more of the soil cation exchange capacity or precipitated NaCl salt may explain the accumulation. During the summer cattle have been seen licking the road shoulders, presumeably for salt.

Area 3 showed a similar pattern except for a net loss of Cl^-. This large net loss of Cl^- is difficult to explain and suggests that the input of road salt was underestimated. Nevertheless, the relatively large loss of Ca^{++}, Mg^{++}, and K^+ from this small area (4.9 ha) is consistent with results from area 2.

Since the dominant effect appears to be a result of road salt application the impact will not be distributed evenly throughout the ski basin area but concentrated along roads, parking lots, and perhaps water courses. The values in Table 3 show average losses per hectare for the entire area which may be misleading. For example, the more remote portions of area 2 no doubt experience nutrient inputs and outputs similar to the more natural area 1. Close to the road, however, the nutrient losses/hectare are significantly higher than those shown for area 2, perhaps 50-fold. These excessive losses must in some way affect the growth and productivity of the organisms in those areas. The literature shows numerous studies of vegetation damaged by road salt, however, I know of no published literature of the effects of road salt on site productivity in the mountainous West. The effects may range from accumulated toxic effects of Na^+ and Cl^- on growth to significant alteration of soil physical properties affecting root and water penetration (McKee and Wolf 1963, Piatt and Krause 1974).

The effects of Na^+ on soil physical properties result primarily from the breakdown of the granular soil structure. Calcium and Mg^{++} in the proper proportions maintain soil in good condition of tilth and structure because their divalent charge and low hydration cause them to be tightly held by soil colloids enhancing the coagulation

of colloid particles. Monovalent Na^+ which is highly hydrated is not tightly held by colloid particles permitting individual particles to repel each other and to stay in dispersion (Brady 1974). In most normal soils Ca^{++} and Mg^{++} are the principal cations held by the soil in replaceable or exchangeable form, with Na^+ consisting of a small percentage (i.e. 3 to 7%, McKee and Wolf 1963). An increase of the percentage Na^+ to as much as 12 or 15% causes the granular soil structure to begin to break down when the soil is moistened. Various changes take place resulting in the sealing of pores and a decrease in soil permeability. With further increases in the Na^+ percentage, the soil continues to deteriorate and its pH increases to the level of alkali soils (McKee and Wolf 1963).

In a normal soil Ca^{++} is present in higher concentrations than Na^+ because of its prevalence in the common minerals of rocks and of soil (Hem 1970) and because of the greater affinity that Ca^{++} has for soil exchange sites (Brady 1974). It is easier for Ca^{++} to replace Na^+ in the exchange complex than for Na^+ to replace Ca^{++}, and unless the Na^+ in the soil solution is considerably in excess of the Ca^{++}, no Ca^{++} will be replaced. However, in areas subject to road salting Na^+ is greatly in excess of Ca^{++} and Mg^{++} and through mass action replaces these ions on the exchange complexes. This appears to be the explanation for the significant losses of Ca^{++}, Mg^{++} and K^+ in areas 2 and 3 of the ski basin. Since Ca^{++} is the dominant base ion in the soil of this area, it should be influenced to the greatest degree by road salt. This seems to explain why Ca^{++} and Na^+ show the greatest change in the stream water of areas 2 and 3 (Figs. 4, 5).

Vegetation requires Ca^{++} in relatively large quantities in relation to Na^{+} or other base elements (Rodin and Basilevich 1967) and the replacement of Ca^{++} by Na^{+} on the exchange sites in soil must reduce the ability of vegetation to obtain Ca^{++} as well as other elements. It is difficult to predict whether this has more effect than deterioration of the soil physical characteristics or Na^{+} and Cl^{-} toxicity, however, the combination of all of these significantly damages vegetation (Piatt and Krause 1974).

THE TRILINEAR DIAGRAM--A TOOL

In many areas where land development is occurring one may not be fortunate enough to have gaged, calibrated watersheds to allow the quantification of nutrient outputs. Therefore, it would be difficult to identify the factor or factors which are primarily responsible based on nutrient fluxes. One method of water quality interpretation which can aid in the identification of major disturbance factors is through the use of the trilinear diagram technique. If one considers only the major dissolved ionic constituents in milliequivalents per liter and lumps K^{+} and Na^{+} together the composition of most natural waters can be closely approximated in terms of three cationic species (Hem 1970). If the values are expressed as percentages of the total milliequivalents per liter of cations, the composition of the water can be represented by a trilinear plotting technique (Fig. 6). Each vertex represents 100% of a particular ion or group of ions. The composition of the water with respect to cations is indicated by a point plotted in the triangle. The coordinates at each point add to 100%.

The most useful application of this technique is testing water quality to determine whether a particular water may be a simple mixture of others or whether it is affected by solution or precipitation of a single salt. It can be easily shown that the analysis of any mixture of waters A and B will plot on the straight line AB in the plotting field (where points A and B are for the analyses of the two components) if the ions do not react chemically as a result of mixing (Hem 1970). Or, if solutions A and C define a straight line pointing toward the Na^+ vertex, the more concentrated solution represents the more dilute one spiked by addition of a Na^+ salt. These characteristics make this method ideal for evaluating the different sources of nutrients in an area in relation to water quality. Figure 6 demonstrates the plotting method for the 3 areas of the Santa Fe Ski Basin. The line for each area represents the range of water chemistry characteristics during the 2 water years. For area 1 the range is quite small with somewhat higher levels of Ca^{++} found in stream water during the high discharge during 1972-73. The high discharge causes the points to fall somewhat closer to the Ca^{++} vertex. The lines for areas 2 and 3 show that all of the water analyses during a 2-year period fall on a straight line between the natural water quality (area 1) and a point representing the chemical makeup of road salt. The interpretation is that the water quality in the areas 2 and 3 is primarily affected by the solution of road salt. During the spring snow melt, water quality analyses plot on the line nearer the Na^+ plus K^+ vertex. Since K^+ changes little over the course of the year this is primarily the result of Na^+ changes. During the fall and winter months (before

snow melt) water quality analyses plot near the line representing natural water quality. Although the water quality of areas 2 and 3 plot on a straight line toward the Na^{+} vertex the two lines shift apart as the influence of road salt decreases. This may be the result of the influence of the sewage input into area 2. It has been shown that sewage accounts for the major input of Mg^{++} to the area (Table 4). Figure 6 also shows the plot representing the chemical analysis of sewage effluent. Since water quality analyses do not plot on a line between natural water quality and sewage effluent, sewage cannot be the major factor affecting water quality. Its effect seems to be minor in this case by slightly increasing the proportion of Mg^{++} at certain times during the year in the immediate area of the source. Current research is trying to verify the minor role of the effect of sewage effluent on inorganic water quality in this area through intensive studies of anions. A similar trilinear plotting method can also be used for major anions and since NO_3-N is significantly higher in sewage effluent than in either natural stream water or road salt the plotting technique should identify which of these two effects are dominant and the period during which each is dominant.

This technique would seem to be a very simple and useful method for a land manager who is responsible for maintaining water quality or evaluating the effects of various practices. A number of portable water analysis kits are available which enable a land manager to make immediate and frequent on-the-spot checks on the health of a particular aquatic or terrestrial ecosystem.

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Table 1. Hydrological data for 3 areas of the Santa Fe Ski Basin. Values are in cm of water.

Area	Year	Precip.	Run-off	Evapo-trans-piration
1	72-73	91.4	86.9	4.5
	73-74	58.2	27.9	30.3
2	72-73	83.1	74.8	8.3
	73-74	54.2	21.7	32.5
3	72-73	74.4	65.5	8.9
	73-74	49.6	17.4	32.2

Table 2. Yearly average concentrations of nutrients in stream water of three areas of the Santa Fe Ski Basin.

	Concentration (mg/l)						
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	NO_3-N	NH_4-N	Cl^{-}
Area 1							
1972-73	3.23	0.68	1.90	0.57	0.29	-	0.3
1973-74	2.94	0.70	1.97	0.59	0.29	-	0.3
1974-75	2.76	0.64	1.71	0.54	0.26	0.07	-
Area 2							
1972-73	4.91	1.06	3.56	0.74	0.51	-	6.4
1973-74	4.88	1.05	3.87	0.88	0.36	-	12.2
1974-75	5.11	1.14	3.81	0.94	0.36	0.08	-
Area 3							
1972-73	5.53	1.15	6.30	0.80	-	-	11.9
1973-74	5.20	1.16	5.02	0.93	-	-	17.1
1974-75	5.76	1.28	5.90	1.02	0.38	0.09	-

Table 3. Nutrient budgets for 3 areas of the Santa Fe Ski Basin during 1972-1974. Values are expressed in kg/ha.

	1972-73			1972-73		
	Precip. Input	Stream Water Output	Net Loss	Precip. Input	Stream Water Output	Net Loss
Ca^{++}						
area 1	7.2	24.5	-17.3	6.3	8.0	-1.7
area 2	7.2	39.1	-31.9	6.4	10.2	-3.8
area 3	7.2	240.6	-233.4	6.4	20.6	-14.2
Mg^{++}						
area 1	0.6	5.0	-4.4	1.0	1.9	-0.9
area 2	0.6	8.5	-7.9	1.0	2.2	-1.2
area 3	0.6	52.9	-52.3	1.0	6.0	-5.0
Na^{+}						
area 1	1.0	13.6	-12.6	0.8	5.3	-4.7
area 2	1.0	28.9	-27.9	0.8	8.1	-7.3
area 3	1.0	482.4	-481.4	0.8	52.7	-51.9
K^{+}						
area 1	2.1	4.3	-2.2	1.1	1.6	-0.5
area 2	2.0	5.8	-3.8	1.2	1.8	-0.6
area 3	2.0	35.3	-33.3	1.2	4.1	-2.9

Table 4. Element budgets for areas 2 and 3 of the Santa Fe Ski Basin during the 1972-73 water year. Values are expressed in kg/total area.

	Inputs			Outputs	
	Precip.	Sewage	Road Salt	Stream Water	Net Gain or Loss
Area 2					
Na^{+}	92	790	3500	2657	+1725
Ca^{++}	662	250	44	3599	-2643
Mg^{++}	55	160	4	784	-565
K^{+}	184	45	28	533	-276
Cl^{-}	156	1100	6125	6458	+923
Area 3					
Na^{+}	5	-	2100	2634	+529
Ca^{++}	35	-	28	1179	-1116
Mg^{++}	3	-	4	259	-252
K^{+}	10	-	16	173	-147
Cl^{-}	7	-	3675	6817	-3135

FIGURE LEGEND

Figure 1. Three study areas on the Santa Fe Ski Basin, New Mexico. The total area of the ski basin is 259.9 ha.

Figure 2. Average daily stream discharge in cfs from area 1 of the Santa Fe Ski Basin.

Figure 3. Stream water concentrations of Ca^{++}, Mg^{++}, Na^{+}, and K^{+} in area 1 of the Santa Fe Ski Basin. These data identify the variability of natural stream chemistry for this area.

Figure 4. Stream water concentrations of Ca^{++}, Mg^{++}, Na^{+} and K^{+} for areas 1 and 2 of the Santa Fe Ski Basin.

Figure 5. Stream water concentrations of Ca^{++}, Mg^{++}, Na^{+} and K^{+} for areas 1 and 3 of the Santa Fe Ski Basin.

Figure 6. Trilinear plotting diagram for the interpretation of water quality. The lines represent the range of water quality characteristics for 3 areas of the Santa Fe Ski Basin during a 2 year period.

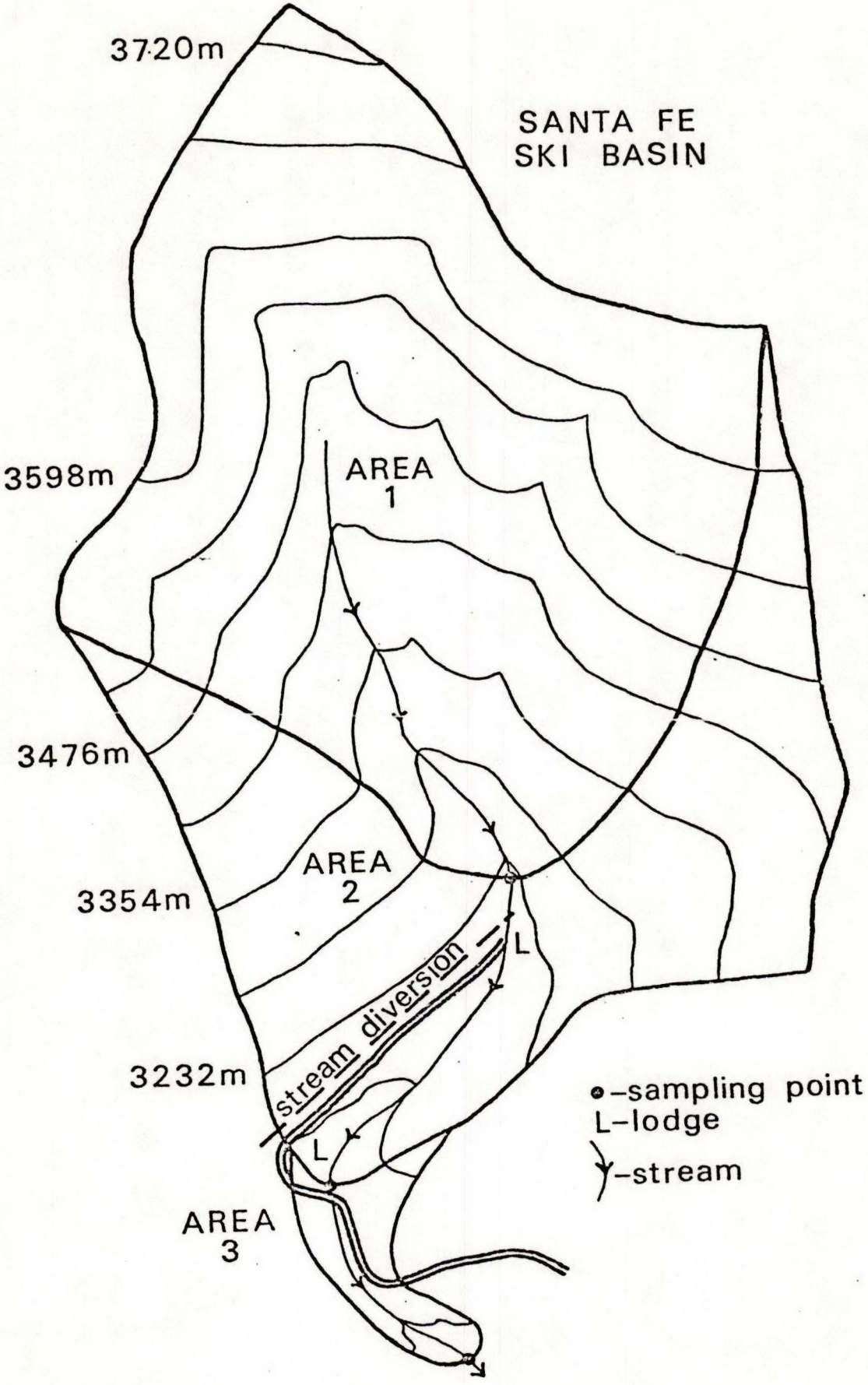

3720m
SANTA FE
SKI BASIN
3598m
AREA
1
3476m
AREA
2
3354m
L
stream diversion
3232m
●-sampling point
L-lodge
L
-stream
AREA
3

Figure 1.

Figure 2.

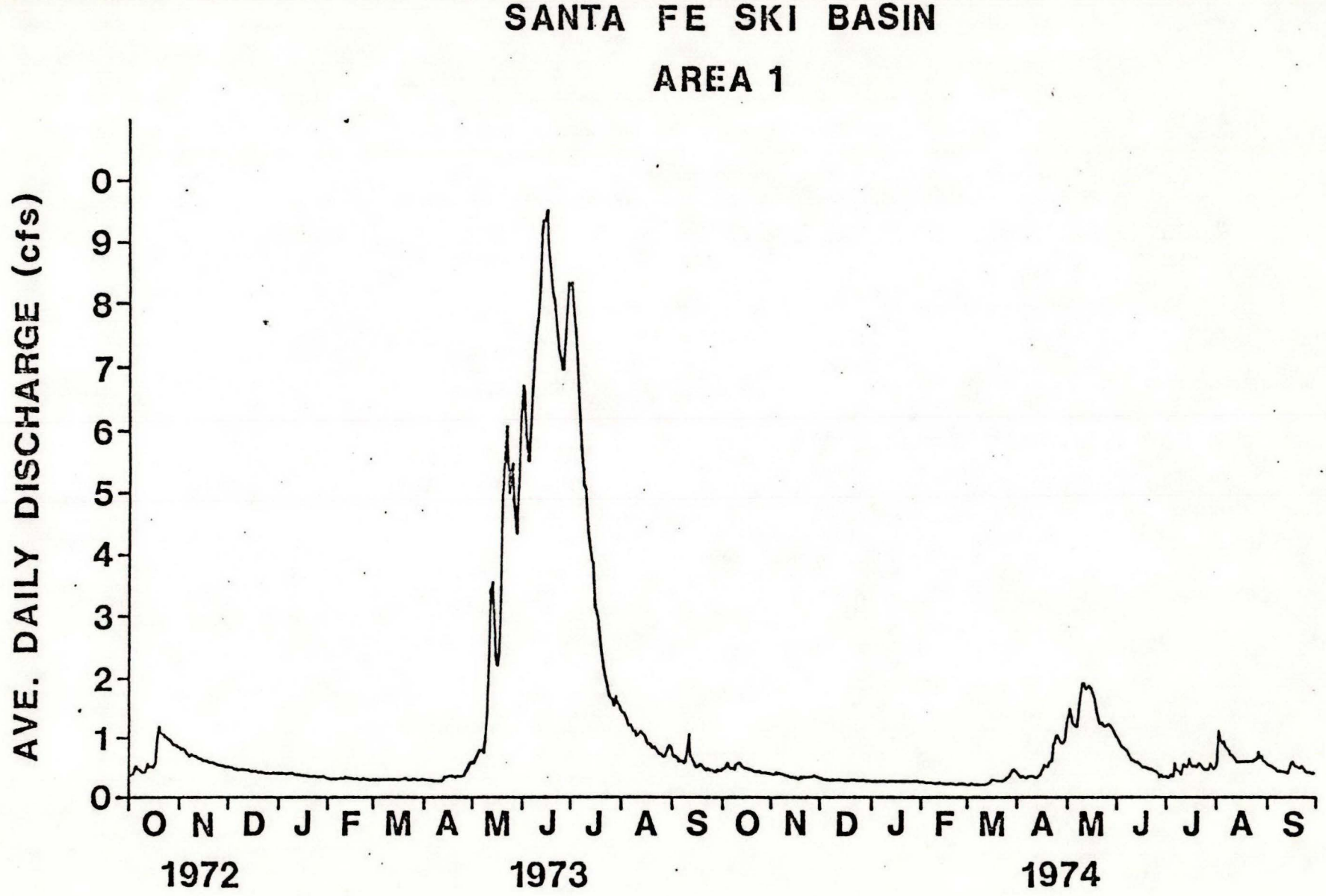
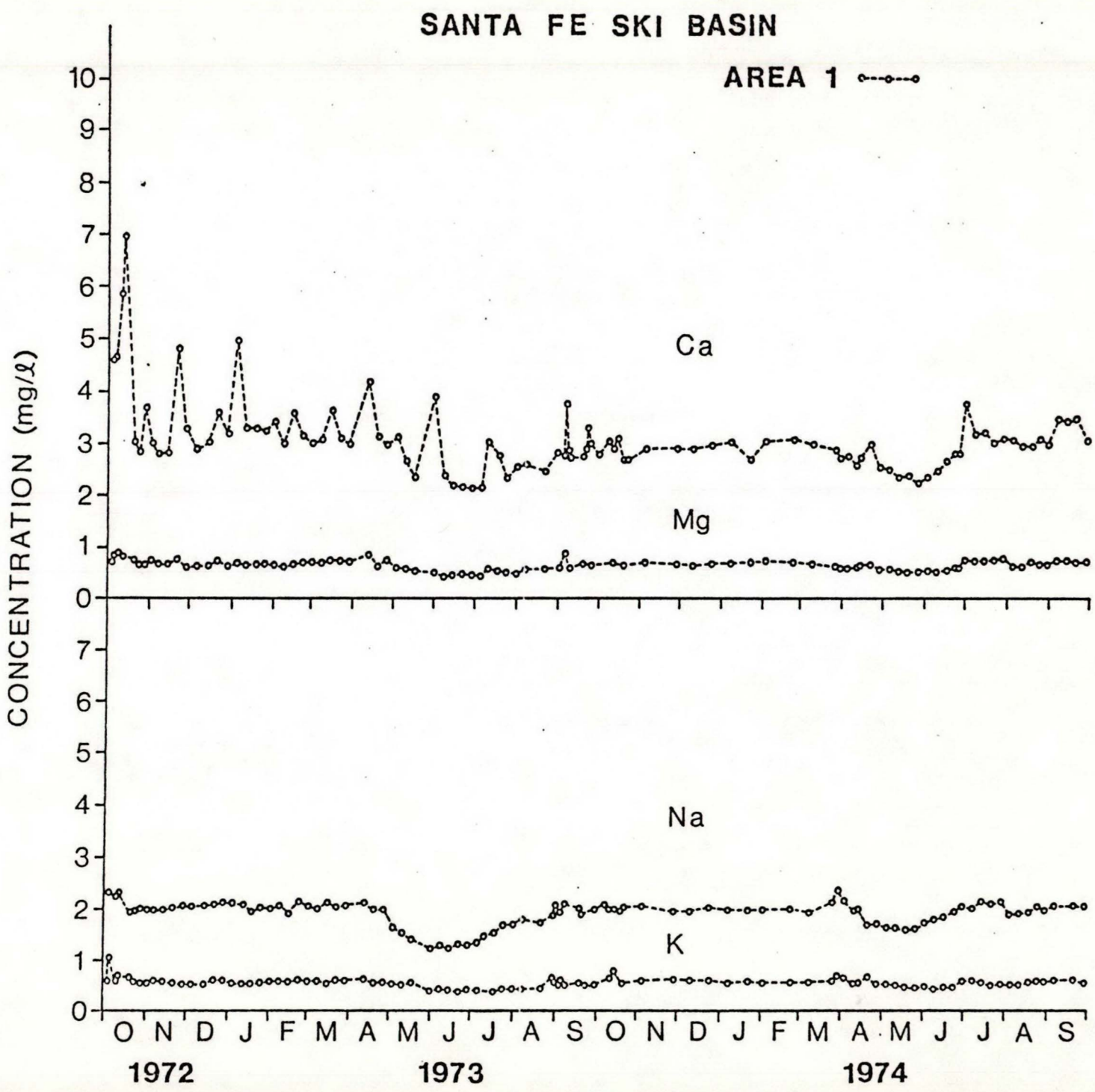

SANTA FE SKI BASIN
AREA 1
AVE. DAILY DISCHARGE (cfs)
0
1
2
3
4
5
6
7
8
9
0
O N D J F M A M J J A S O N D J F M A M J J A S
1972
1973
1974

Figure 3.


SANTA FE SKI BASIN
AREA 1
CONCENTRATION (mg/ℓ)
Ca
Mg
Na
K
10
9
8
7
6
5
4
3
2
1
0
O N D J F M A M J J A S O N D J F M A M J J A S
1972
1973
1974

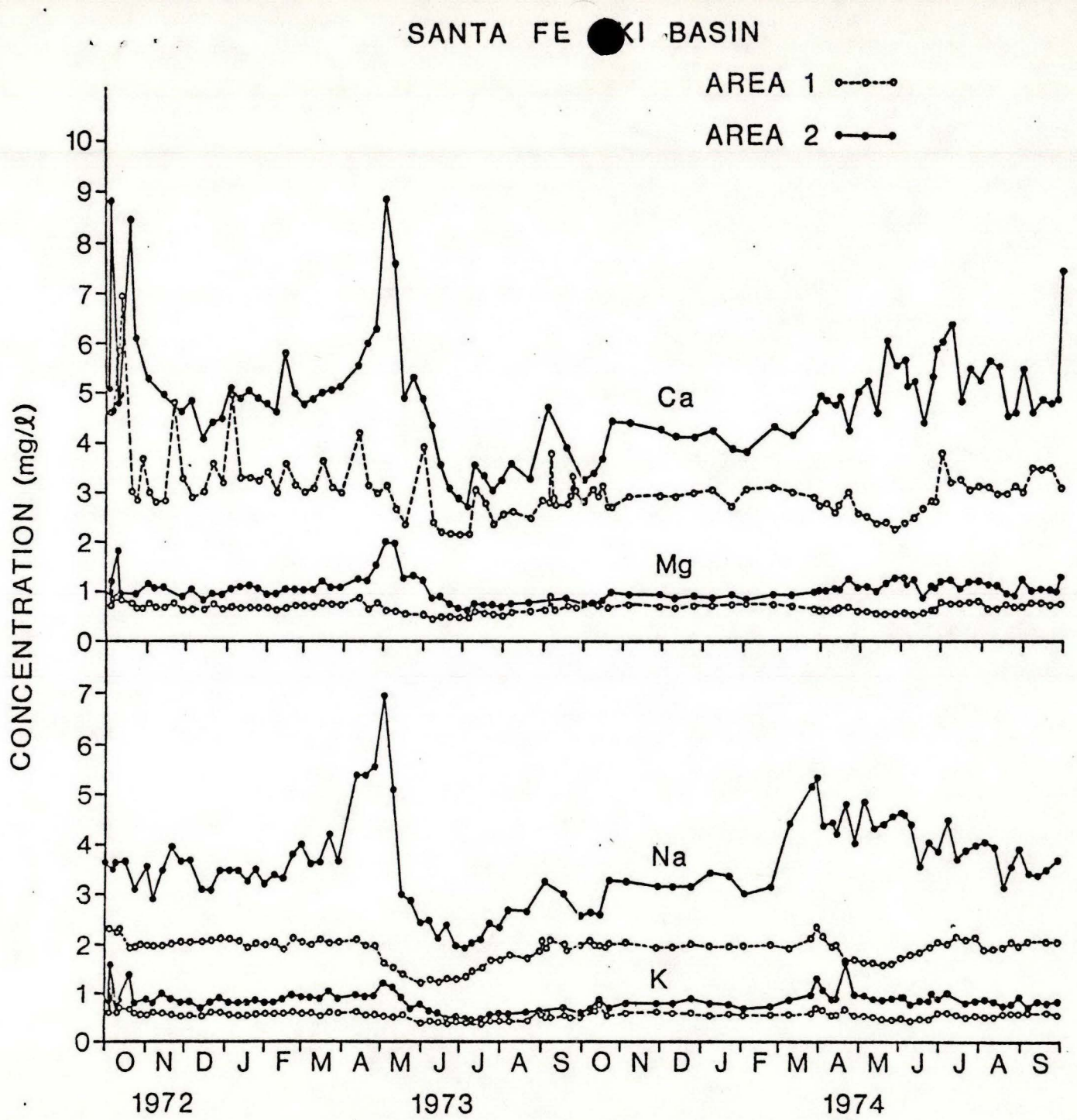

SANTA FE [redacted]KI BASIN
AREA 1
AREA 2
CONCENTRATION (mg/ℓ)
Ca
Mg
Na
K
O N D J F M A M J J A S O N D J F M A M J J A S
1972
1973
1974

Figure 4.

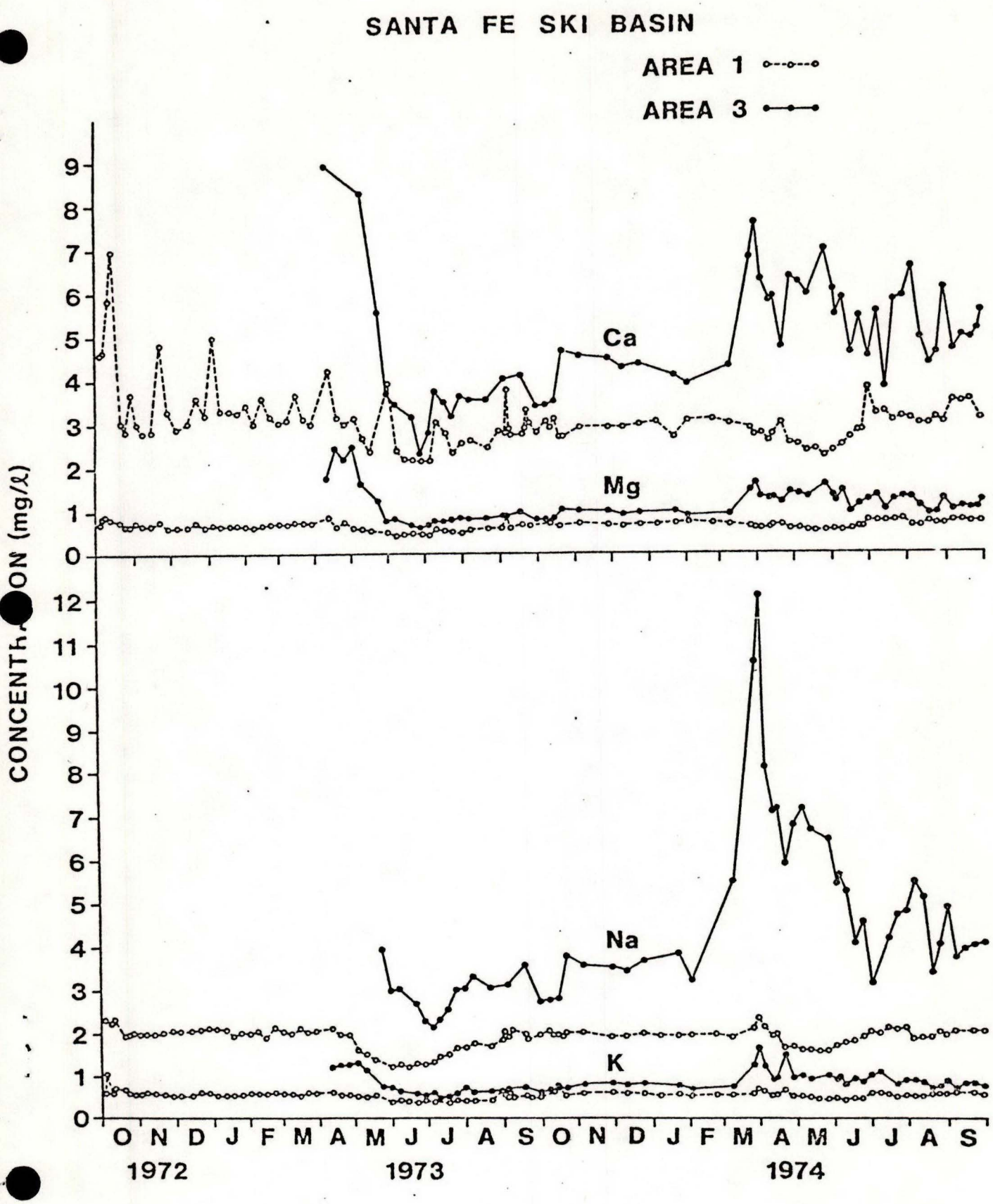

SANTA FE SKI BASIN
AREA 1
AREA 3
CONCENTRATION (mg/ℓ)
Ca
Mg
Na
K
0
1
2
3
4
5
6
7
8
9
10
11
12
O N D J F M A M J J A S O N D J F M A M J J A S
1972
1973
1974

Figure 5.

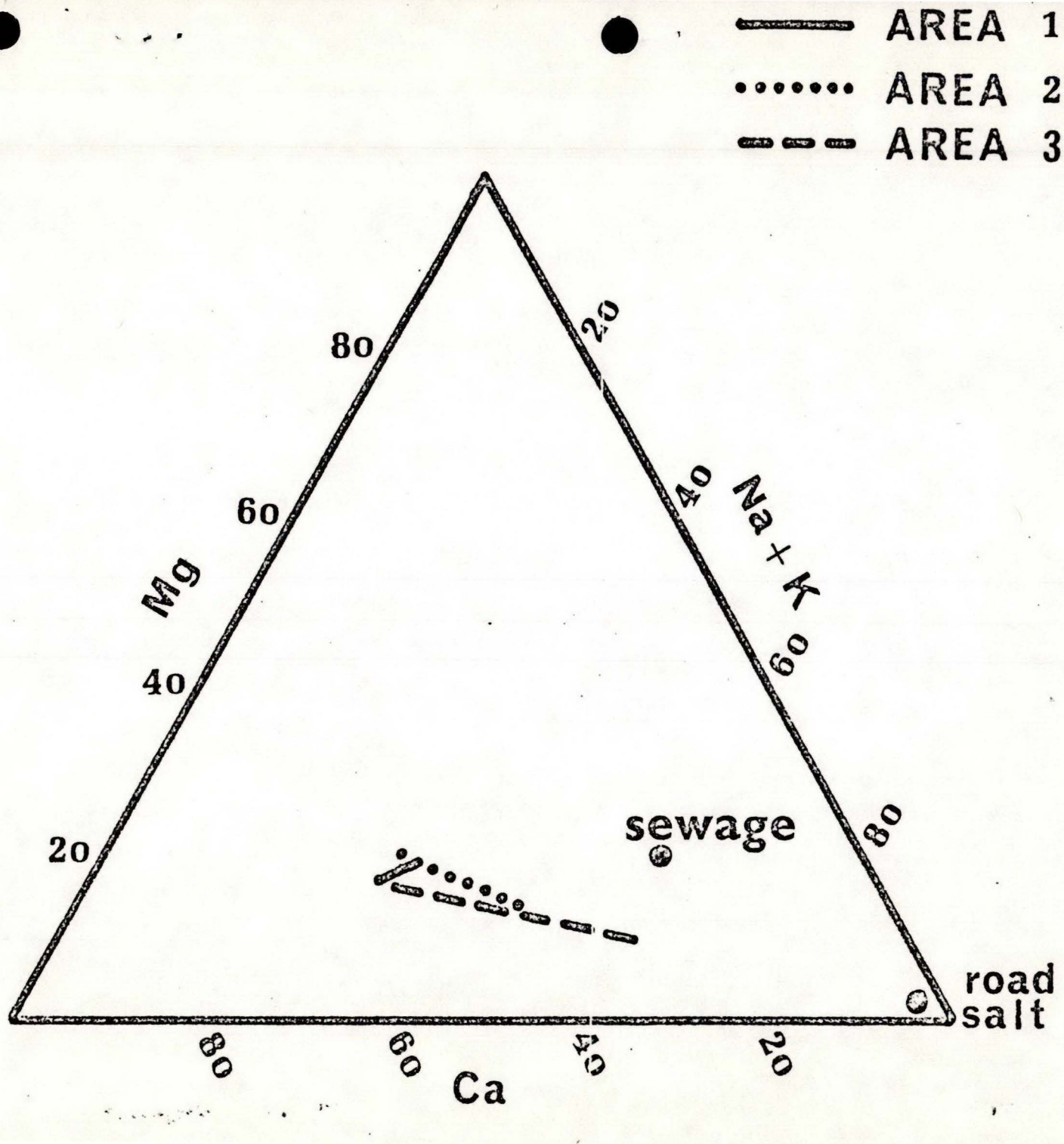

AREA 1
AREA 2
AREA 3
80
20
60
40
Mg
40
60
Na + K
20
80
sewage
road salt
80
60
40
20
Ca

Figure 6.